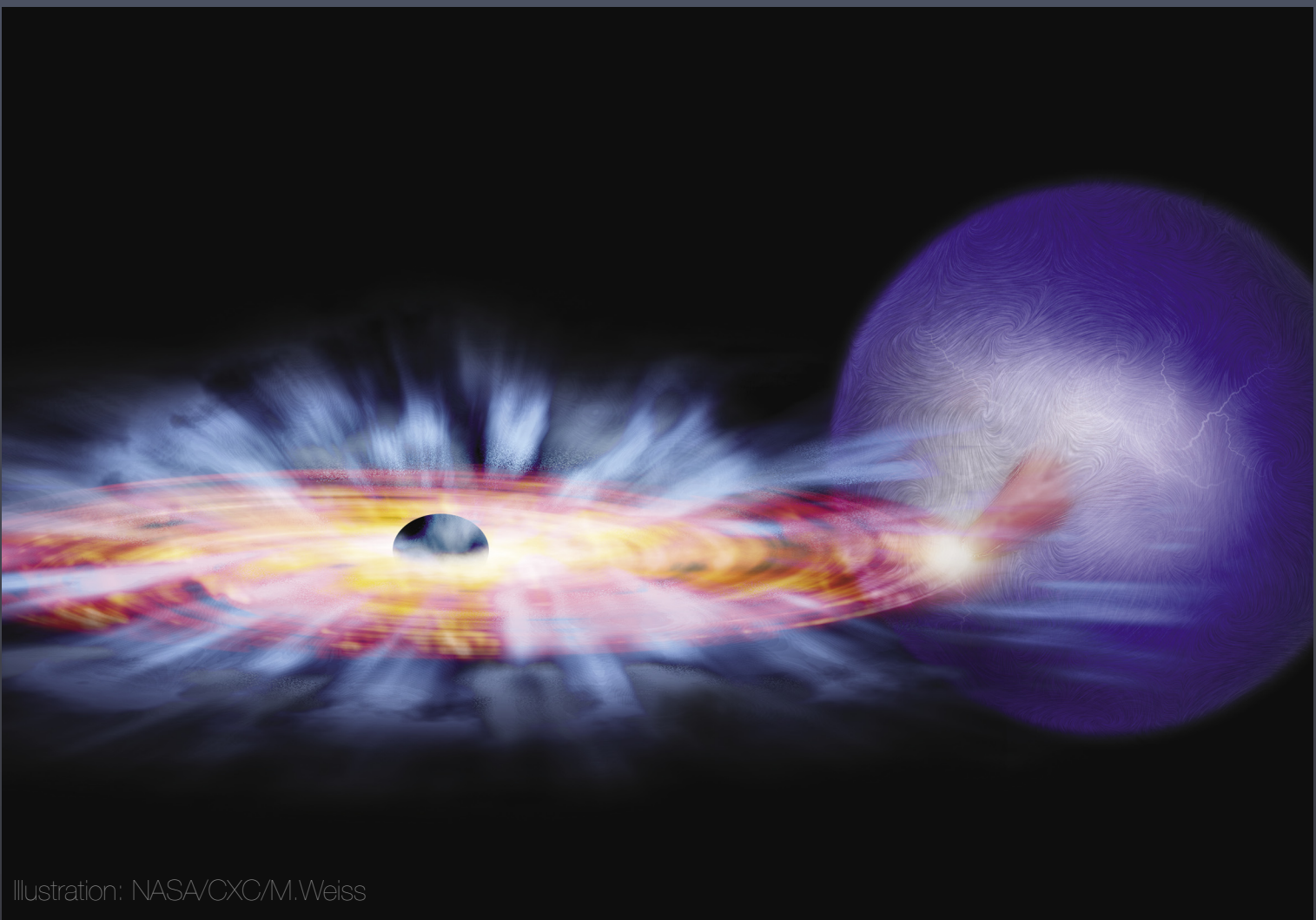


# Black holes: Gravity in the Extreme

You’ve probably heard of black holes – objects where a tremendous mass is concentrated into a region so small that its extreme gravity allows nothing to escape its clutches – not even light. Well, they have a few other incredible features.



*This binary consists of a black hole and a normal star (in blue). Gas is being pulled away from the star and falling onto a disk (red) spinning around the black hole. Some of this gas spirals in towards the black hole, generating copious amounts of light.*

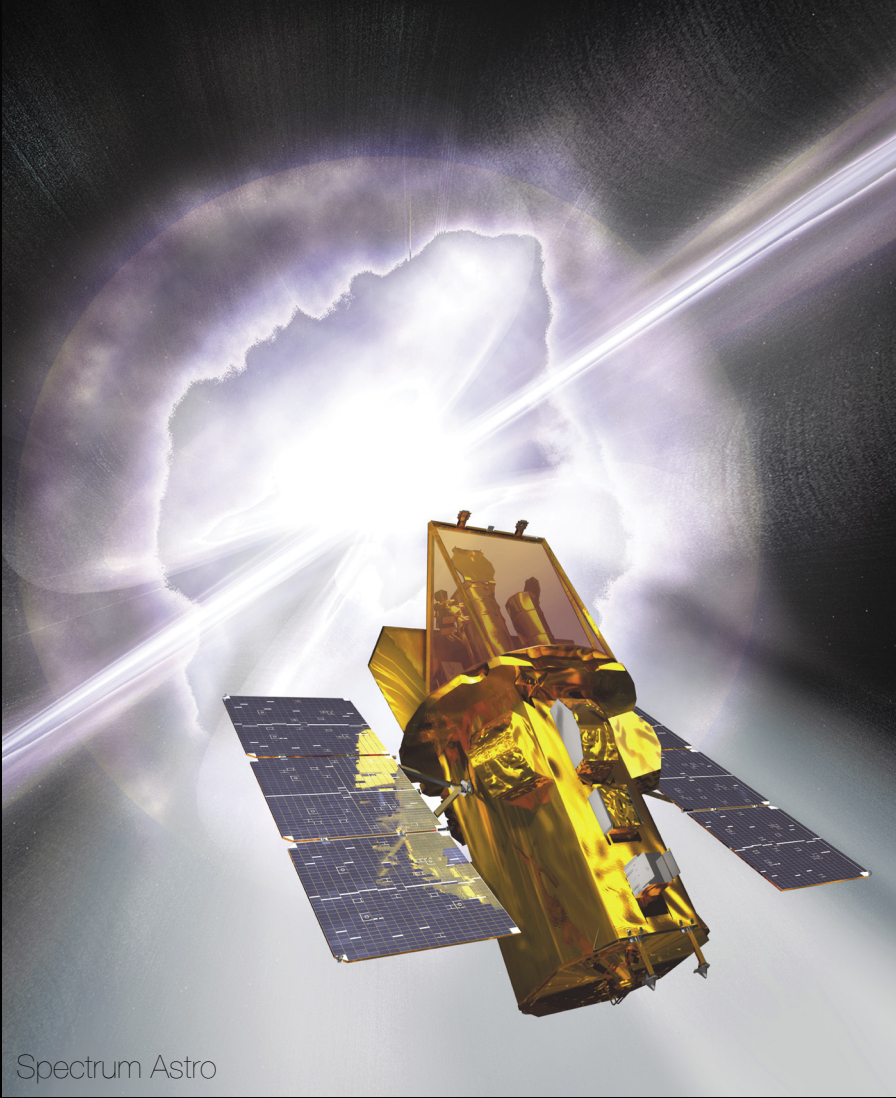
Though invisible, these bizarre objects can profoundly affect their surroundings. Their intense gravity pulls off surface material from companion stars that then settles into a disk around the black hole. The gas in this orbiting disk heats up to millions of degrees and produces X-rays that we can detect and study.

There are at least two types of black holes:

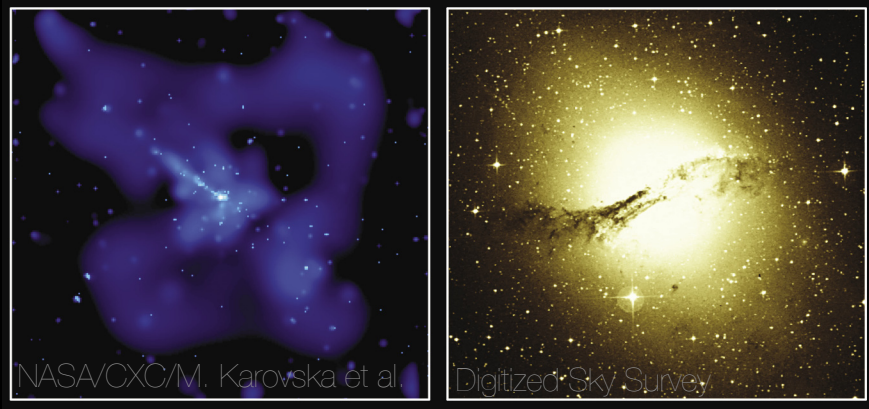
- **Stellar-sized black holes** are 3 to 20 times as massive as our Sun. They form when a star burns all of its nuclear fuel, explodes as a supernova, and collapses under its own gravity.
- **Supermassive black holes** lurk in the cores of galaxies like our Milky Way. They can be billions of times more massive than the Sun, but nobody knows exactly how they are formed.

**Did you know?**  
The Sun will never become a black hole. It’s not nearly massive enough.

On occasion, supernovae release enormous amounts of gamma rays, the most energetic form of light. Gamma-ray bursts (GRBs) blast out in just seconds more energy than the Sun will ever generate. Among other amazing discoveries, the Goddard-led Swift mission has revealed that most GRBs are the birth cries of black holes.



*An artist’s rendering of the Swift spacecraft observing a gamma-ray burst.*

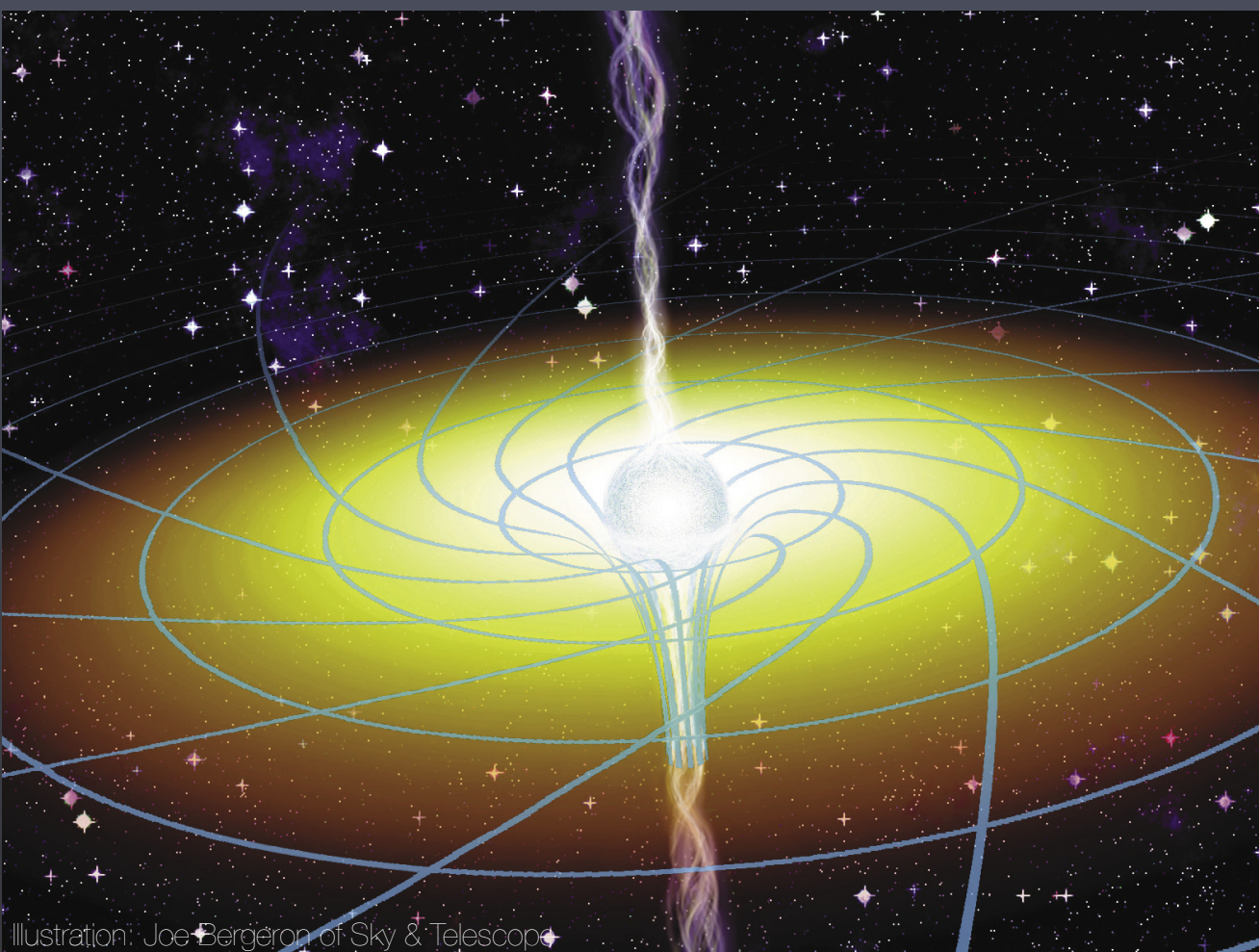


*Centarus A: An X-ray jet (left) blasts out from the central black hole in this galaxy. In the visible image (right), a band of dust and gas obscures the supermassive black hole.*

Goddard scientists routinely use data from X-ray satellites such as Chandra, Suzaku, and the Rossi X-Ray Timing Explorer to advance our knowledge of black holes. Goddard is also developing an even more powerful X-ray observatory, Constellation-X, which will shed more light on these exotic objects. Constellation-X is a major project in NASA’s “Beyond Einstein” program, a series of missions to explore some of the underlying physics behind Einstein’s theories.

# You Can't Hide a Black Hole

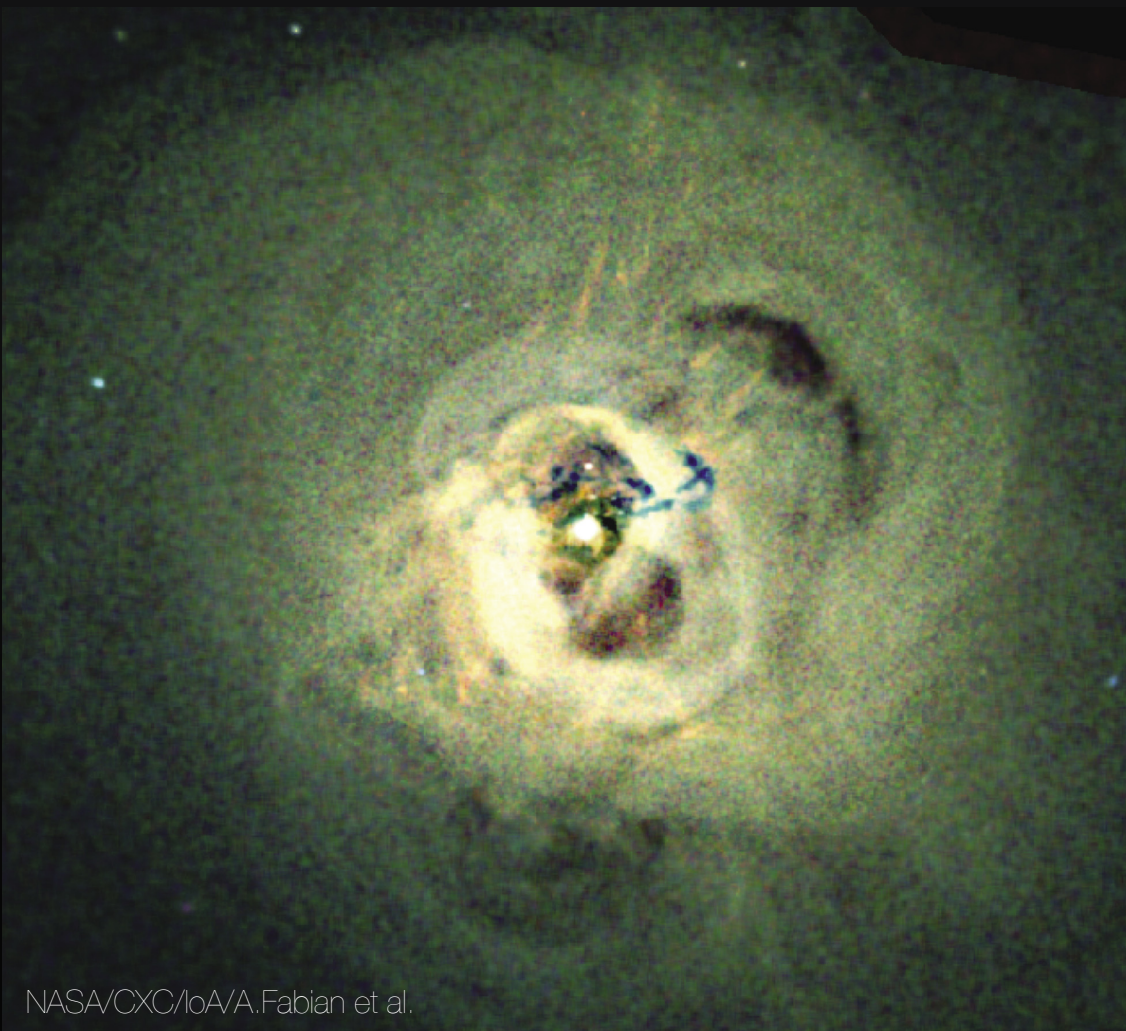
Strange things happen near black holes. Time seems to slow to a crawl, and space itself is twisted. Although Einstein predicted these effects, they were too weird to be taken seriously at the time. Black hole study truly began with the start of X-ray observations of the Universe in the 1960s. And we learned that Einstein was right.



*This illustration of frame dragging shows a black hole's rotation twisting the fabric of space and time. As material in the disk crowds inward, some gases are squeezed outward to become jets.*

Einstein predicted that, because their gravity is so strong, rotating black holes would drag space and time with them as they spun. Powerful X-ray satellites like Chandra, the Rossi-X-Ray Timing Explorer, XMM-Newton, and Suzaku have detected the effects of time slowing near black holes, and the effects on matter orbiting black holes due to the dragging of space. Measuring their spin also provides clues about how they formed.

Supermassive black holes, millions to billions of times as massive as the Sun, are found in the centers of most galaxies. Though extremely small compared to their host galaxies, they can cause

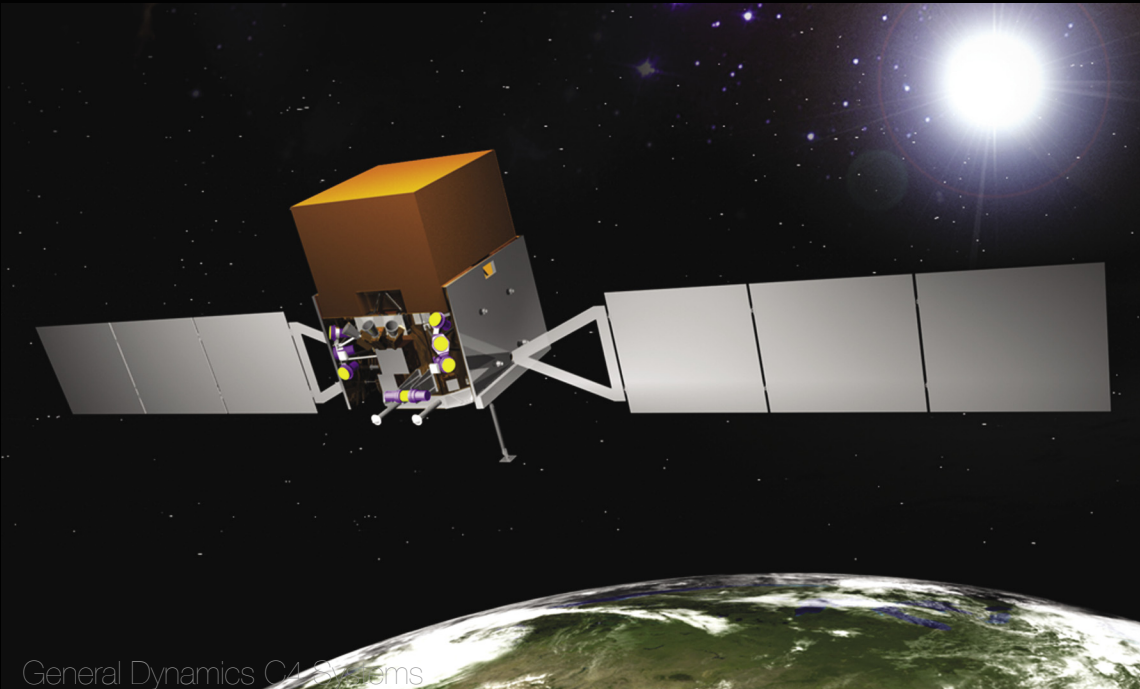


*Chandra observations of the central regions of the Perseus galaxy cluster reveal evidence of the many supermassive black holes and their effects on these thousands of galaxies.*

commotion on a very large scale. These powerhouses can generate winds that carve out enormous holes in their galaxies – and even in their galaxy clusters (hundreds to thousands of galaxies). They can even control the growth of those galaxies.

**Did you know?** Black holes don't ramble around the Universe sucking up planets and stars like vacuum cleaners. They move like other stars, affecting only the area nearby.

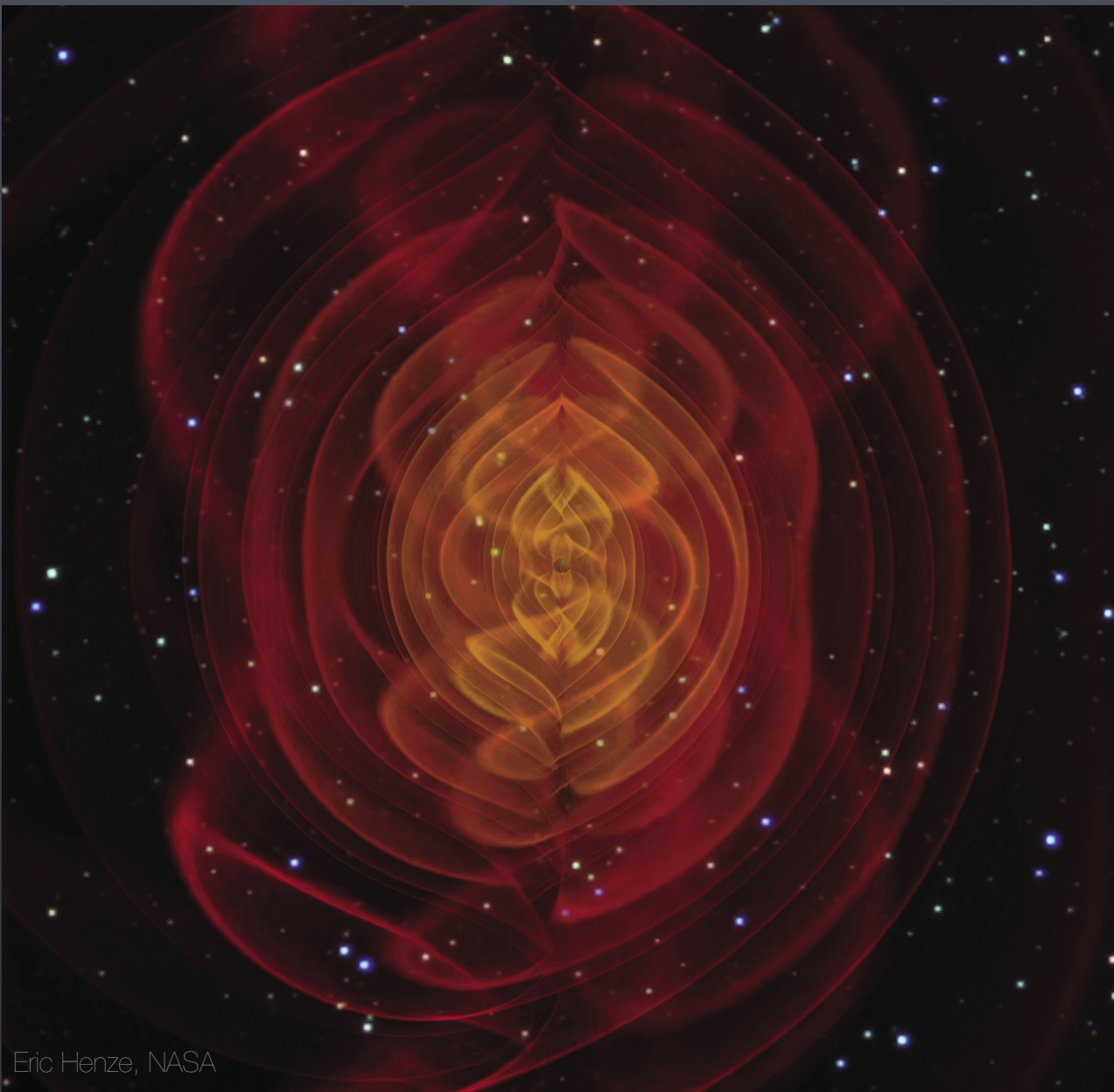
Black holes spew out huge jets of matter and energy traveling at 99% the speed of light, but we don't yet know exactly how the jets form. The Gamma-ray Large Area Space Telescope (GLAST) mission will measure the gamma rays – the most energetic form of light – produced by these jets. It will help scientists find new jets and study them in unprecedented detail. GLAST, developed by Goddard and partner institutions around the world, will be more sensitive and view a larger region of the sky than any previous gamma-ray observatory.



*Artist's rendering of the GLAST spacecraft in orbit.*

# When Black Holes Collide, Space Trembles

How do you disturb the fabric of spacetime? According to Einstein, massive objects like black holes orbiting or colliding with each other, or collisions of giant stars would do it. These violent scenarios release unimaginable amounts of gravitational energy that move out from the scene at the speed of light.

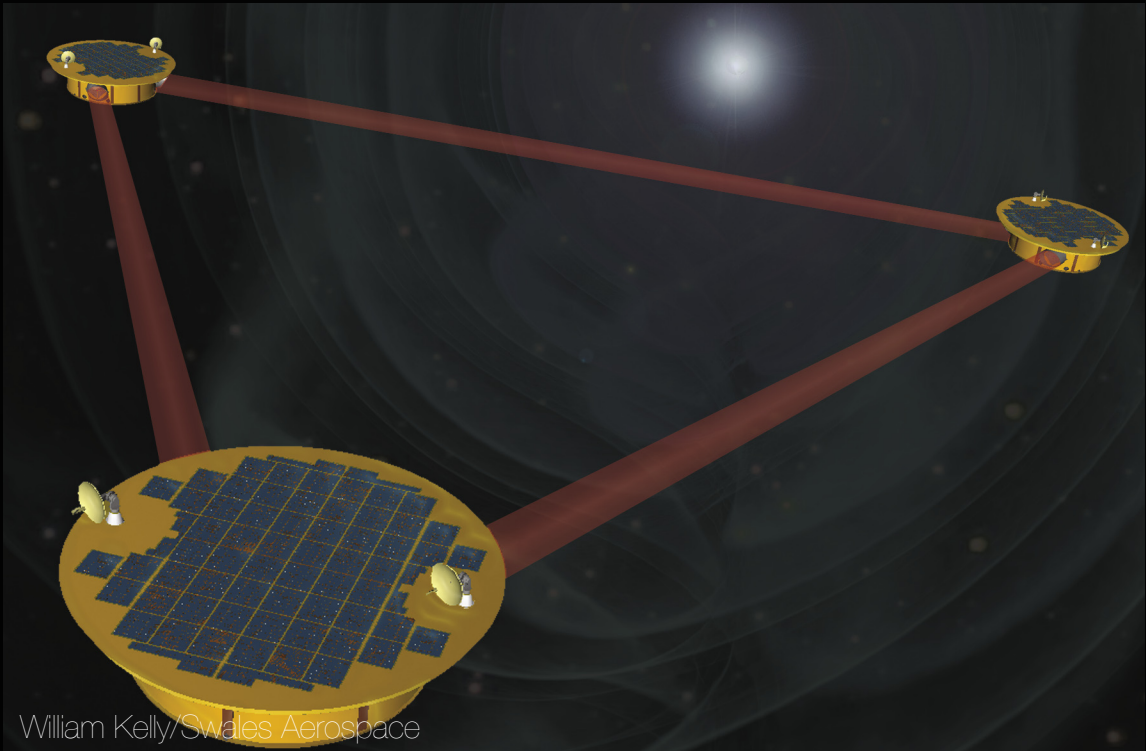


*The red contour lines represent gravitational waves created when two black holes are about to collide.*

Gravitational waves travel out into space like ripples from a stone tossed into a lake. As expected, the larger the event, the stronger the gravitational waves. But waves from even these mammoth events weaken while traveling great distances to us. This makes them extremely tricky to find. In 1993 the Nobel Prize in Physics was awarded for the first indirect evidence of their existence.

Scientists haven’t yet detected gravitational waves directly, but the race is on to do so. The ground-based Laser Interferometer Gravitational-Wave Observatory (LIGO) will locate nearby supernovae, or mergers of neutron stars or stellar-mass black holes, by detecting very-high-frequency gravitational waves. But mergers of supermassive black holes in distant galaxies emit waves at a much lower frequency.

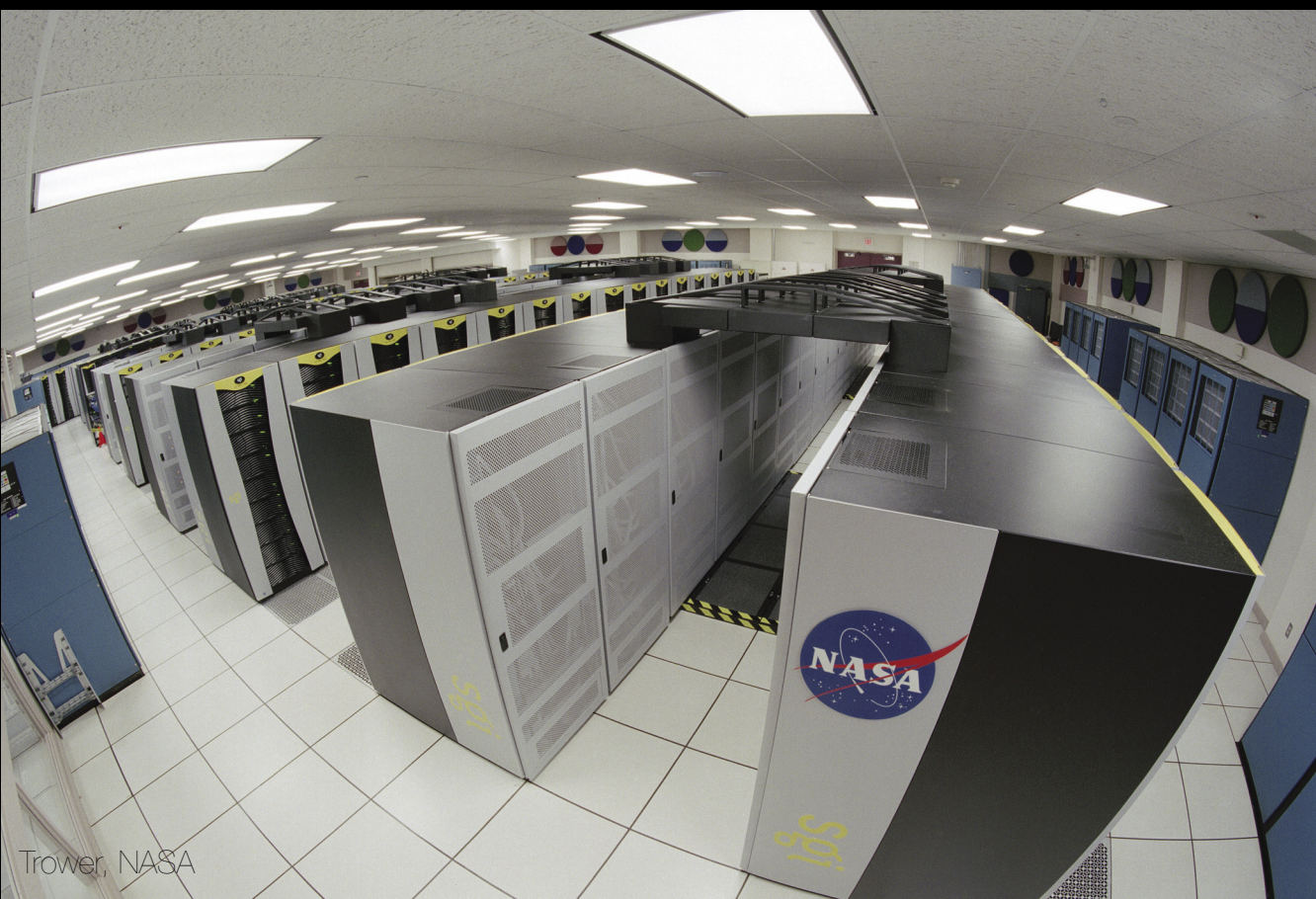
**Did you know?**  
At the instant when two huge black holes merge, they release about as much gravitational energy as all the stars in the Universe.



*An artist's rendering of the three LISA spacecraft.*

Goddard is playing a central role in an international effort to build the first space mission to detect the objects LIGO cannot. The Laser Interferometer Space Antenna (LISA) consists of three spacecraft that will respond to passing gravitational waves just as buoys respond to ocean waves. LISA is one of several missions in NASA’s “Beyond Einstein” program to study black holes, dark energy, and other phenomena predicted by Einstein.

While preparing for LISA to be launched, scientists are creating computer models of what gravitational waves from colliding black holes would look like. After decades of work on this important problem, Goddard scientists were among the very first to successfully make those calculations.



*The NASA Advanced Supercomputing Facility used for the gravitational wave calculations.*